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From the Managing Editor

Satellite communications has transformed our world and the way we see it. Dramatic technological advances and entrepreneurial creativity have linked nations and people together, brought shared experiences to the world, and provided services undreamed of only 25 years ago when these systems began. As impressive as previous advancements have been, they may well be dwarfed by the introduction of new satellite communications technology in the 1990s. —NTIA Telecomm 2000

Ideally, the prospect of advancement applies to people as well as to technology. After nearly 10 years with JPL — five of those with the Communications Technologies Program — I am going back to school, joining the Interdisciplinary Telecommunications Program at the University of Colorado at Boulder for an advanced degree in Telecommunications, emphasizing policy and economics.

Laura Randall, formerly of the Public Service Satellite Consortium in Washington, D.C., will assume most of my SATCOM-related responsibilities. Laura was the Government and External Relations Manager for NASA's Advanced Communications Technology Satellite (ACTS) Program and was Managing Editor of the *ACTS Quarterly*. She was also a liaison between the ACTS Program and Congress, industry and the media, and coordinated the ACTS experiment solicitation process. She will be performing some of these same functions for the ACTS Mobile Terminal experiments program. I am extremely pleased to welcome her to JPL's Communications Technologies Program and its technology transfer and industry relations activities.

Randy Cassingham's role as editor and publisher of the *SATCOM Quarterly* will be expanded to include the managing editor's duties.

Another addition to JPL's Communications Technology Program is Richard Romer, who recently became the lead technologist for the Government Agency Mobile Satellite Services Task. Dick has over 20 years of experience in software and systems engineering for military communications systems. He is also the Communications System Engineer for the All Source Analysis System Project, an Army tactical information system. He will be working closely with Valerie Gray to transfer Mobile Satellite System technology to Federal and state government agencies.

I look forward to working with many of you again. Satellites will keep us in touch.

Laura C. Steele

Laura C. Steele
Managing Editor

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The Satellite Communications (SATCOM) Program is managed by the Jet Propulsion Laboratory for the National Aeronautics and Space Administration. The goals of this Program are to develop advanced system concepts and technologies in the areas of mobile, micro and personal communications. A major thrust of the Program through the mid-1990s is the development of the mobile terminal to operate with NASA's Advanced Communications Technology Satellite.

ACTS Aeronautical Experiments

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During the past decade, NASA and JPL have been involved in technology and system concept development to demonstrate the viability of mobile satellite communications at L-band. With the launch of the Advanced Communications Technology Satellite (ACTS) planned for early 1993, NASA and JPL are now concentrating on developing Ka-band terminal technology in preparation for satellite field tests. These experiments will permit the characterization of Ka-band, thereby helping to determine its feasibility for mobile satellite communications. In addition to a land mobile experiment [1], a low bit rate (2.4/4.8 kbps) aeronautical experiment is being planned for early 1994 and a high bit rate (less than 500 kbps) follow-on experiment is being proposed.

There is a demand for high-quality, reliable voice and data satellite communication links between aircraft and ground stations to improve air traffic management services and to meet the growing demand for passenger communications services. These links are important because they should result in increased passenger and crew safety and reduced flight time and operational costs by optimizing the aircraft's flight path [2].

In 1988, the Future Air Navigation Systems (FANS) Committee of the International Civil Aviation Organization proposed L-band satellite communications as a method of enhancing and augmenting the services provided by the current communication, navigation and surveillance systems. Some of the proposed new services were safety related, others were not. Examples in the first category were direct air traffic controller to aircrew communications, automatic aircraft position reporting (such as the service that will be implemented by the Automatic Dependent Surveillance system) and air traffic services such as providing flight information and operational control communications. Included in the nonsafety-related services were private correspondence among aircraft operators, known as Aeronautical Administrative Communications, and public or passenger correspondence [3].

The possibility of experimentation with ACTS provides an opportunity to test new aeronautical satellite concepts, to characterize Ka-band, to develop Ka-band hardware and to determine the readiness of Ka-band technology to provide aeronautical communications services. This article describes two aeronautical experiments using ACTS. The first, the low bit rate experiment, will establish a 4.8-kbps link between an aircraft and a ground station. This experiment is planned for late 1993 or early 1994. It will be primarily a Ka-band technology demonstration and will permit an initial characterization of the Ka-band aeronautical channel. The second experiment, the high bit rate experiment, has been proposed to NASA for late 1994. It would demonstrate a 64–384-kbps satellite link between an aircraft and a ground terminal. This link would serve to demonstrate new aeronautical system concepts such as aeronautical satellite link connection with the Aeronautical Telecommunications Network, compressed video transmission and reception, satellite beam handover strategies, aircraft uplink power control and multiple cabin and cockpit channels with call priority assignments. Many of these concepts are important to the successful implementation of an aeronautical satellite communication system regardless of its frequency of operation.

Both experiments will establish the aeronautical link in a similar manner. The experiment setup is shown in Figure 1. The satellite uplink is at 30 GHz; the downlink is at 20 GHz. The Link Evaluation Terminal (LET) at NASA Lewis Research Center (LeRC) will be used as the fixed-Earth station or hub station. ACTS will be set to

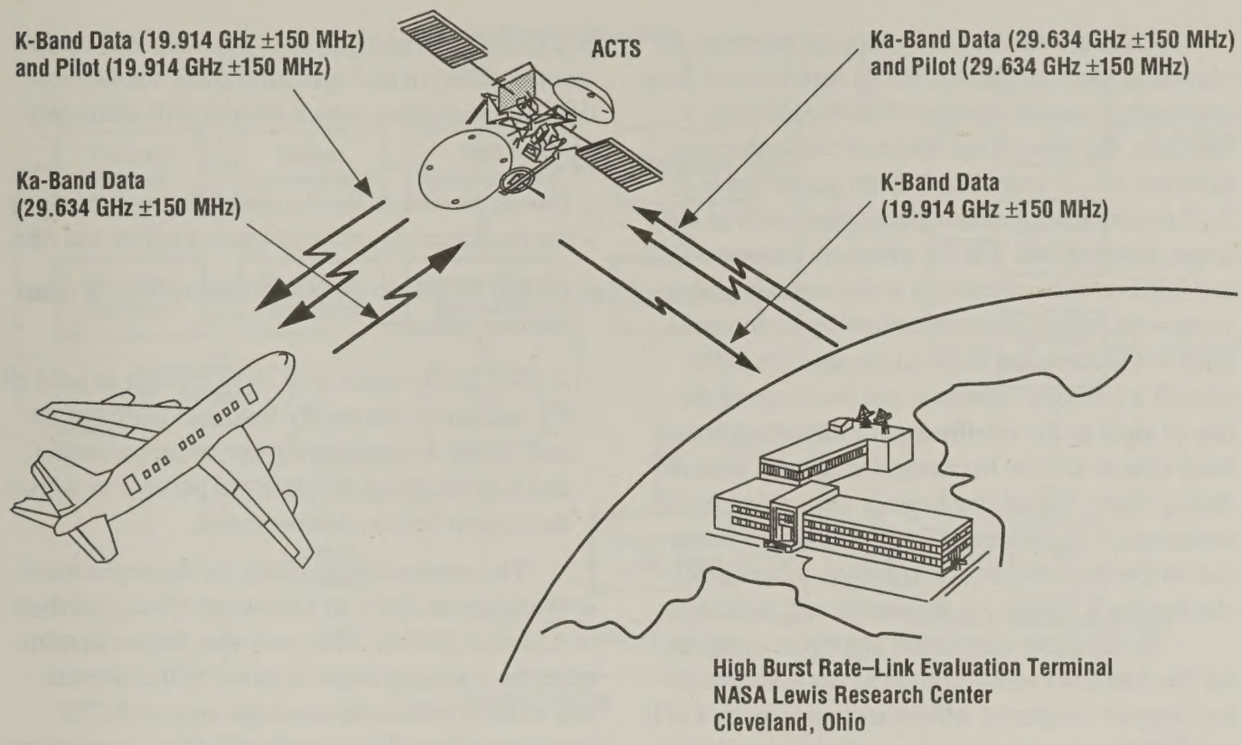
K-Band Data (19.914 GHz ±150 MHz)
and Pilot (19.914 GHz ±150 MHz)
ACTS
Ka-Band Data (29.634 GHz ±150 MHz)
and Pilot (29.634 GHz ±150 MHz)
Ka-Band Data
(29.634 GHz ±150 MHz)
K-Band Data
(19.914 GHz ±150 MHz)
High Burst Rate–Link Evaluation Terminal
NASA Lewis Research Center
Cleveland, Ohio

Figure 1. Aeronautical experiment setup.

the Microwave Switch Matrix mode. In this mode, ACTS receives up to three simultaneous signals from its 30-GHz receive antennas and switches the downconverted incoming signals to upconverters, which are connected to ACTS' 20-GHz transmit antennas. Both experiments will use modified versions of the transceiver and baseband processor being developed for the land-based version of the ACTS Mobile Terminal (AMT) [1]. In the forward link, pilot and data signals will be transmitted from the fixed terminal to the aeronautical mobile terminal. The pilot tone is used for signal acquisition and tracking, downconversion of the forward data signal and Doppler precompensation for the transmitted data signal. The two forward link signals will occupy one ACTS transponder. In the return link, the aeronautical mobile terminal will transmit one data channel to the fixed terminal. This signal will occupy a second ACTS transponder. In the low bit rate experiment, the aeronautical mobile terminal will utilize three different proof-of-concept electronically steered, phased-array antennas being developed under contract for LeRC and the Air Force's Rome Laboratory. The aeronautical mobile terminal will use the AMT's mechanically steered antennas to support the higher bit rate link. Thus, both experiments will capitalize on the equipment commonality between the land and aeronautical mobile experiments to reduce the need for separate terminal development.

The Low Bit Rate Experiment

The main objectives of the low bit rate experiment are to:

- Establish and demonstrate a reliable duplex communications link between the aircraft and a fixed hub station via ACTS for low bit rate voice and data transmission.
- Demonstrate and evaluate Ka-band monolithic microwave integrated circuit (MMIC) antenna arrays for aeronautical mobile use.
- Characterize the Ka-band channel for aeronautical communications, principally during aircraft cruise.

The challenges associated with the operation of a Ka-band aeronautical mobile satellite system are enumerated in this article. Those associated with performing the low bit rate aeronautical experiment include operation of the antennas and antenna controller, modifications to the land mobile terminal transceiver and baseband processor to handle the larger aeronautical Doppler offsets and Doppler rates and maintenance of a reliable duplex link with ACTS' scanning beam.

Although electronically steered antennas are viewed as ideal candidates for an aeronautical communication system because of their conformal structure, the operational limits of these antennas have not, to our knowledge, been quantified in a field experiment. Antenna parameters such as scan angle, tracking rate and the more conventional G/T and EIRP will be calculated in the aeronautical environment, which is characterized by large variations in the elevation angle to the satellite in the aircraft's frame of reference and blockage of the line of sight to the satellite by the aircraft structure. Both effects are due to changes in aircraft attitude during flight. Signal blockage or shadowing in the aeronautical environment is quite different from that in the land mobile environment, where most shadowing is caused by vegetation and buildings.

The Doppler estimation algorithm designed for the AMT [4] was designed to work accurately for Doppler frequency offsets and rates up to 4 kHz and 250 Hz/sec, respectively — those expected for the land mobile satellite experiment. Table 1 gives the expected Doppler offsets and rates in the aeronautical mobile satellite communications experiment. Both the Doppler estimation algorithm and the Doppler correction circuit, which is realized in the IF converter, will require modification to handle the more challenging aeronautical channel specifications.

ACTS is currently scheduled to be launched in late February 1993. The low bit rate aeronautical experiment will commence soon after the first phase of the land mobile satellite communications experiment is completed.

Although the test aircraft has not yet been selected, the most likely choice is either a Boeing 737 or a Lear 25. In addition to availability and equipment installation and operating costs, the key criteria in determining which aircraft will ultimately be used are:

- It must be able to fly at a speed that will produce the maximum Doppler frequency offset and rate.
- It must be able to fly at altitudes typical of commercial jetliners.
- It must have a cabin area large enough to hold all the equipment necessary for the experiment, as well as the accompanying operating personnel and a small group of interested persons to whom the system will be demonstrated.

The proposed flight path for the experiment is Washington, D.C., to Cleveland, Ohio, and then to Chicago, Illinois. This path was chosen to minimize the scanning angle required of the antenna and to keep within the coverage area of ACTS' west scan beam. The aircraft will fly in areas where the beam's G/T and EIRP fall more than 3 dB below its maximum. Thus, an interesting characteristic of the experiment will be the variation in signal strength transmitted to and from the aircraft.

Aeronautical Terminal Description

Figure 2 diagrams the aeronautical terminal, which is made up of three major components: the baseband processor, the microwave processor and the antenna system. The baseband processor consists of the modem, terminal processor, speech codec and data acquisition system (as described in [1]). The microwave processor consists of the RF upconverter (also described in [1]). The antenna system consists of three experimental active array

Table 1. Aeronautical Doppler offsets and rates under various conditions at frequencies of 20 and 30 GHz.

Doppler offset or rate	20 GHz	30 GHz
Doppler offset for true airspeeds		
450 knots	15.4 kHz	23.1 kHz
500 knots	17.1 kHz	25.7 kHz
Doppler rate due to linear acceleration		
10 ft/sec^2	203 Hz/sec	305 Hz/sec
20 ft/sec^2	406 Hz/sec	609 Hz/sec
Doppler rate due to gravitational force		
1 g (32 ft/sec^2)	650 Hz/sec	975 Hz/sec

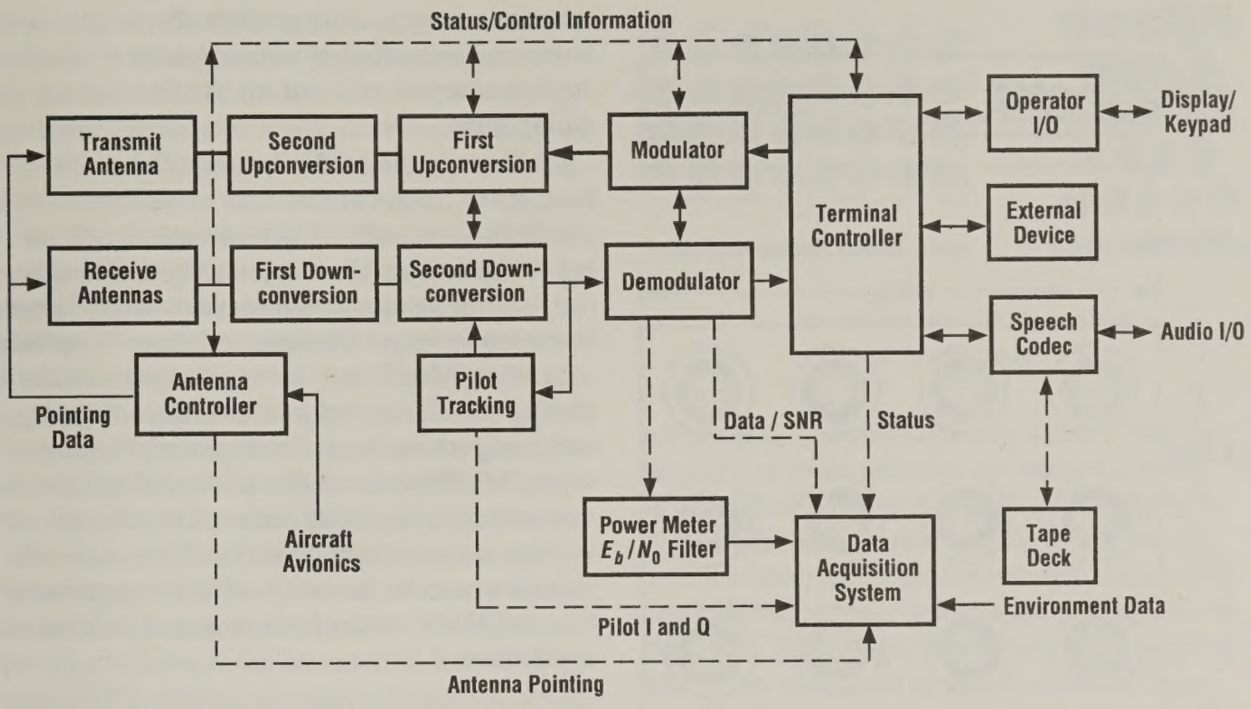

Figure 2. Aeronautical terminal block diagram.

antennas — two for receiving and one for transmitting — and their accompanying antenna controller.

The antenna system includes three experimental active arrays. Each array incorporates MMIC amplifier and phase-shifter devices at every radiating element for distributed amplification and electronic beam steering. The MMIC arrays are being developed through LeRC and the Air Force Rome Laboratory/Milstar Terminal Program Office contracts to advance MMIC device insertion technology for space and aeronautical applications. The arrays are experimental precursors of future Ka-band systems and offer electronic scanning performance in compact, lightweight packages that can be flush-mounted on an aircraft's exterior surface to minimize aircraft drag and cabin intrusion.

The single 30-GHz transmitting antenna is a 4×8 array consisting of two adjacent 4×4 MMIC subarray modules. The 16-element, 30-GHz MMIC subarray modules, presently under development by Texas Instruments for LeRC, represent one of the most ambitious MMIC insertion programs attempted to date. The subarray module, shown in Figure 3, features a high-density, multilayer "tile" configuration that integrates 32 30-GHz MMIC chips. The radiating elements are cavity backed, aperture coupled, linearly polarized microstrip patches arranged on a 4×4 grid. Beam steering and distributed power amplification are provided by a 4-bit phase shifter and a constant gain amplifier at each radiating element. Development of the proof-of-concept subarray is being sponsored by the NASA Office of Aeronautics and Exploration Technology.

Two different 20-GHz MMIC receive arrays will be provided through a cooperative effort with LeRC, the Air Force's Rome Laboratory and the Air Force Milstar Terminal Program Office. In this effort, small MMIC receive arrays will be provided as subtasks to existing Rome/Milstar development contracts. These contracts, awarded to Boeing and GE in late 1990 (dual award), focus on the design of full-scale (approximately 4,000 elements) integrated-circuit, active phased-array (ICAPA) transmit and receive antennas suitable for Milstar aircraft terminals and on the fabrication and delivery of 100-element proof-of-concept subarrays. In the subtasks to the existing contracts, GE and Boeing will each deliver a small (16 and 23 elements, respectively) 20-GHz MMIC receive array suitable for the low bit rate experiment. The small GE and Boeing arrays are being sponsored jointly by the ACTS Project Office and the Milstar Terminal Program Office.

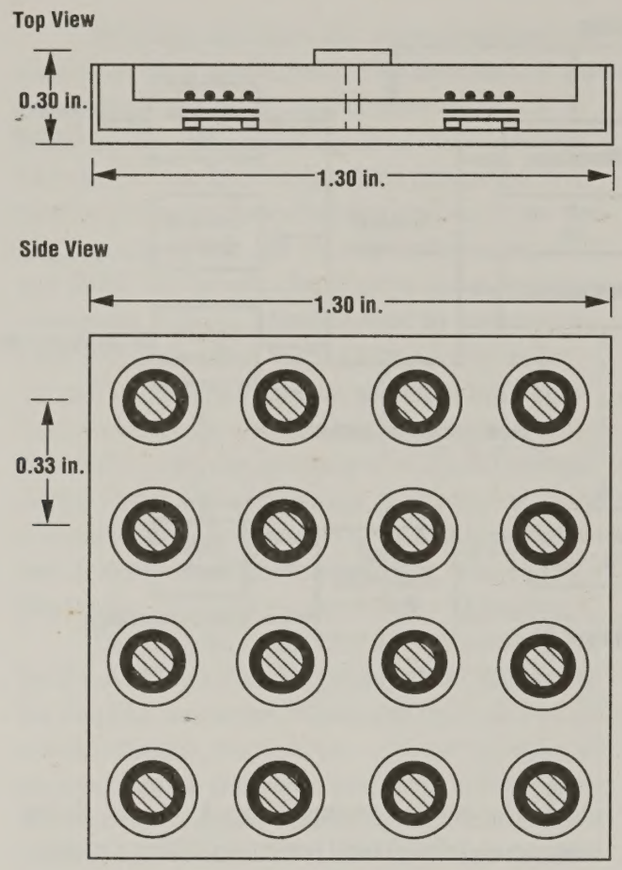

Figure 3. Aeronautical transmit antenna subarray module.

Both Boeing and GE use a "brick" configuration to achieve closely spaced radiating elements. Their designs, however, involve fundamentally different packaging concepts. The GE array consists of 16 printed-circuit dipole elements arranged in a 2×8 parallelogram. The array is formed by two plug-in cards or trays, each having eight dipole radiating elements along one edge, eight MMIC phase shifters and eight MMIC low-noise amplifiers (LNAs). The Boeing array consists of a cluster of 23 waveguide modules (three rows of five alternating with two rows of four) in a hexagonal grid pattern. Figure 4 shows the element geometry of the antennas. The radiating elements are dielectrically loaded circular waveguides into which an MMIC phase shifter and an MMIC LNA are integrated. As configured for the low bit rate aeronautical experiment, both the Boeing and the GE arrays will be linearly polarized.

The steering of all three arrays will be set by a single master open-loop controller developed by LeRC. The controller's interface with the aircraft's avionics will provide continuous aircraft position and attitude updates. Due to the limited number and the relatively small size (number of elements) of the three proof-of-concept arrays, full hemispherical coverage is not possible. The arrays, however, have sufficient scanning range to allow the demonstration of automatic satellite tracking during flight.

Having three fundamentally different Ka-band MMIC arrays available for experimentation and demonstration in the same aeronautical terminal provides an excellent opportunity to assess the merits of the respective approaches to MMIC insertion in active arrays. The acquired data will provide insight into MMIC array system design issues, including overall size and geometry, element type and configuration, beam forming/combining networks, MMIC device characteristics, MMIC device packaging, scanning performance, thermal management and flight durability. These data will provide a basis for the design of future operational Ka-band MMIC arrays for aeronautical terminal applications.

The Proposed High Bit Rate Experiment

The objectives of the high bit rate experiment are to

- Establish and demonstrate a reliable duplex communication link between an aircraft and a fixed hub station via ACTS for compressed video, voice, data and fax transmission.
- Characterize the Ka-band channel for aeronautical communications during the three phases of flight (takeoff, cruise and landing).
- Evaluate aeronautical satellite communication system concepts common to both L-band and Ka-band.
- Assess the performance of current video compression algorithms in a satellite communication link.
- Demonstrate and evaluate the use of mechanically steered antennas — and high G/T electronically steered antennas if available — for aeronautical mobile terminal use.

The maximum bit rate to be supported by the high bit rate experiment has not yet been decided, as this decision has a strong implication for the cost of building the high bit rate aeronautical terminal. The highest data rate discussed to date is 384 kbps for the forward link and 112 kbps for the return link (based on the link budget calculations). The

lowest bit rate for this experiment has been nominally set at 64 kbps — the highest rate supported by the current AMT modem. If the experiment is performed at this rate, it will allow transmission or reception of compressed video and accompanying audio.

The higher rates of 112 kbps and 384 kbps will permit the demonstration of increasingly higher quality video and audio signals, or the multiplexing of one compressed video signal at 64 kbps and several low bit rate voice, data and fax signals. The highest (384 kbps) rate for this experiment would permit a demonstration of a multiple-channel system that could meet the needs of both the cockpit and the cabin. Priority preemption schemes activated by real-time calculation of the link margin could then be tested. No matter which data rate is chosen, the performance of video compression schemes in the aeronautical link will be assessed. In addition, aeronautical system concepts such as satellite beam handover strategies, aircraft uplink power control and aeronautical satellite link connection with the Aeronautical Telecommunications Network will be studied, demonstrated and evaluated. Because these concepts can be applied to aeronautical satellite communications irrespective of their frequency of operation, there is currently a great deal of interest in evaluating them.

The desire to study the Ka-band channel during takeoff and landing, as well as during cruise, is motivated by the need to provide communications to the cockpit and possibly the cabin during these times. Although a satellite communication link between the aircrew and the ground will be utilized only when it is not possible to use existing lower cost communication systems, it is still important to understand whether Ka-band satellites can provide a backup link at all times during flight. In addition, passengers may wish to communicate with associates on the ground when the aircraft is queued up to take off or circling over an airport for landing — not just when it is at cruise altitudes.

When the aircraft is in the airport, the satellite link is more prone to shadowing, multipath and rain attenuation. Because the largest aircraft banking and attitude angles are most often encountered when the aircraft is taking off and landing, the satellite link at those times will be prone to high Doppler rates, shadowing of the direct line of sight to the satellite from the aircraft itself and multipath — not to mention possible rain attenuation. When the aircraft is at cruise altitudes, the satellite link will be most likely to encounter the highest Doppler offsets, minimum shadowing (due only to the aircraft structure) and minimum rain attenuation. (Because aircraft at cruise altitudes are generally above the clouds, it is unlikely that the aircraft-to-satellite link will be obstructed by rain attenuation. Occasionally, thunderheads may block the line of sight to the satellite, but this is considered to be very rare.)

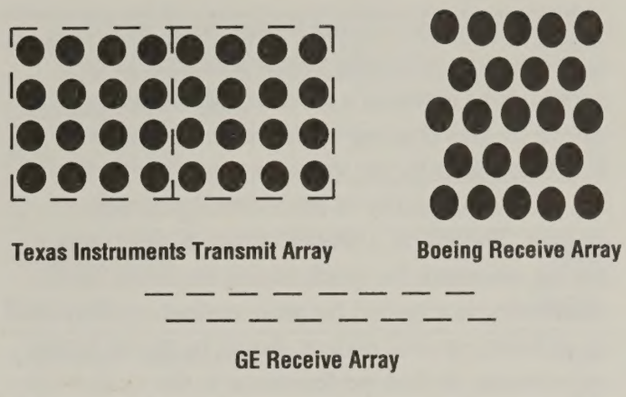

Figure 4. Element geometry of aeronautical antenna arrays.

Maintaining the satellite link during the three phases of flight places a great deal of importance on selecting the appropriate location of the antenna on the aircraft, as the antenna system must be capable of nearly hemispherical coverage. The issue of antenna location (although the optimum location depends on the aircraft used) is included in the last objective of this experiment.

Ka-Band Aeronautical Communications Channel

The communications channel of an aeronautical mobile system is exposed to several potential impairments: rain attenuation, high Doppler shifts and rates and shadowing and multipath fading. In addition, the use of satellites and transceiver equipment at Ka-band creates challenging channel conditions, such as large frequency offsets, phase noise and — in the particular case of using ACTS — nonlinearities in the transponder channel.

Shadowing due to vegetation and buildings can be a problem during takeoff and landing, but not at cruise elevations. However, shadowing due to aircraft structures for a specific flight path or banking maneuvers resulting in low elevation angles can be a potential problem in all phases of flight [5]. This problem can be remedied by selecting a proper antenna location for a specific aircraft type and/or by using antennas with near-hemispherical scanning coverage. The magnitude of

shadowing in the channel is important, as it can cause the loss of timing synchronization in the aeronautical terminal's modem. When this loss of timing is passed along to the video expansion board and seen by the video expansion algorithm, the perceived quality of the video signal may change. Therefore, a proper choice of the symbol timing estimator for quick timing recovery from shadowing is required for aeronautical applications. In addition, several codecs should be tested in this experiment, as their performance in the shadowed aeronautical channel may vary from that found in an additive white Gaussian noise channel.

Multipath fading is not expected to be a problem if a directive antenna with a gain of 20 dB or more is used [6], although some link performance degradation can be expected during banking and at low elevation angles.

Ka-band aeronautical communications links for aircraft flying at low altitudes (i.e., below clouds) may be hindered by rain attenuation. In addition, the satellite-to-hub station link will also be susceptible to rain attenuation at Ka-band, no matter what the altitude of the aircraft. The severity of this problem depends on the geographical location of the hub station Earth terminal and its EIRP and G/T. The effects of rain attenuation on link availability, and hence, link performance, have been determined through the use of an annualized rain-fade model [7]. Link availability is calculated below to be greater than 99.9% for bit rates from 384 to 64 kbps. These calculations assume the following: rain attenuation only in the satellite-to-hub station link, the use of a hub station with the LET Earth station parameters and hub station location in Cleveland, Ohio. These availabilities are thought to be applicable to satellite communication links when the aircraft is at cruise altitudes and underscore the reason why Ka-band is seen as very attractive for aeronautical mobile communications.

Lastly, the use of Ka-band transceivers and satellites brings about channel impairments. Ka-band local oscillators possess larger frequency errors than lower frequency local oscillators because of the larger multiplication coefficients of the frequency stability over temperature and aging specifications. Phase noise increases as well. Demonstration of aeronautical communications with ACTS must take into account the nonlinearities in the transponder channel caused by hard limiters prior to the microwave switch matrix and by the operation of upconverter amplifiers and output signal TWTAs at or near saturation.

Challenges

There are several challenges associated with the high bit rate aeronautical experiment:

- Finding appropriate techniques to compensate for the severe Doppler offsets and rates and to estimate residual offsets and rates.
- Designing additional robustness into the modem to handle potential shadowing problems.
- Selecting the optimum antenna location.
- Modifying the antenna platform to permit tracking in elevation and azimuth.
- Redesigning the antenna pointing and control system.
- Choosing the appropriate video codec.

The motivation for the first three issues has been discussed in detail in the preceding sections; the motivation for the last three issues will be given here. The design of the aircraft antennas, platform and pointing and control system may be the most challenging aspects of aeronautical mobile satellite communications. In addition to performance requirements, operational antenna systems must meet several industry requirements imposed by ARINC, the Radio Technical Commission for Aeronautics (RTCA) and other agencies [8]. No antenna design will be performed in this experiment, as the experiment has already been planned to take advantage of the performance of the AMT's mechanically steered antennas (G/T = –8 dB/K and $EIRP_{max}$ = 32 dBW and 22 dBW for the reflector and active array antennas, respectively). The second-generation versions of the electronically steered antennas described in the next section may be utilized in this experiment if their performance is high enough to maintain the required link rates. The modifications to the AMT antenna platform will involve reconfiguration of the antenna platform, the beam steering commands and the antenna pointing system. This is an ongoing effort at JPL.

In addition, the pointing and control system of the AMT antenna will need to be redesigned to cope with the far more challenging conditions during flight, such as those that occur when the aircraft is banking or flying through turbulence. The an-

tenna pointing and control system may be connected to the aircraft's avionics electronics, such as its inertial navigation system or the Global Positioning System.

Due to the power limitation on the return link (from aircraft to ACTS to ground), the choice of picture quality versus data rate may be a potential challenge for the designer. The required bit error rate (BER) for these video codecs is typically 10^{-5} to 10^{-6}, higher than that needed for voice communications. When operated at lower BERs, most video codecs have serious audio distortion and intermittent video "tiling" effects. Therefore, in order to select a proper video codec, a tradeoff between the required BER and the data rate versus the available link power should be performed. There are many commercial video compression products available on the market that employ a variety of techniques implemented in hardware and/or software. Ideally, several codecs should be tested in this experiment, since none have been designed for transmission over a channel with time-varying characteristics, such as an aeronautical satellite channel.

Proposed Experiment Setup

Figure 1 illustrates a typical scenario for the proposed aeronautical mobile experiment. ACTS will have three types of spot beams: fixed, electronically scanning and one mechanically steerable beam [9]. The AMT antenna has been designed for operation with the Los Angeles/San Diego beam, so it transmits horizontally polarized signals and receives vertically polarized signals. Use of the AMT antenna requires operation with ACTS' similarly polarized antennas, unless a 3-dB penalty is taken.

In order to remain compatible with the AMT equipment, the NASA ground station will transmit the signal at 29.634 GHz to ACTS, and the aircraft will receive at 19.914 GHz for the forward link. In the return link, the aircraft will also transmit at 29.634 GHz, and the ground station will receive at 19.914 GHz.

Link Budget Computation

The link budget computation for the ACTS aeronautical mobile experiment is similar to that shown in Tables 2 and 3. The AMT baseline modulation technique (DBPSK with a rate 1/2, constraint length 7, convolutional code) is

Uplink: NASA/LeRC to ACTS	Value
Transmitted EIRP, dBW	65.00
Pointing loss, dB	–0.00
Space loss, dB	–213.48
Frequency, GHz	29.63
Range, km	38,000
Atmospheric attenuation, dB	–0.47
Polarization loss, dB	–0.50
G/T, dB/K	22.50
Pointing loss, dB	–0.50
Bandwidth, MHz	900.00
Received C/N_0, dB-Hz	101.15
Transponder SNR_{in}, dB	11.61
Limiter suppression, dB	–5.00
Transponder SNR_{out}, dB	6.61
Downlink: ACTS to aero AMT	**Value**
Transmitted EIRP, dBW	55.56
Pointing loss, dB	–0.50
Space loss, dB	–209.89
Frequency, GHz	19.91
Range, km	37,408
Atmospheric attenuation, dB	–0.37
Polarization loss, dB	–0.50
Radome loss, dB	–0.00
G/T, dB/K	–24.98
Pointing loss, dB	–0.50
Downlink C/N_0, dB-Hz	47.42
Overall C/N_0, dB-Hz	47.42
Required E_b/N_0, dB	6.00
Modem implementation loss and loss due to phase noise, dB	2.50
Total E_b/N_0, dB	8.50
Fade allowance, dB	1.00
Data rate, kbps	4.80
Required C/N_0 efficiency, dB-Hz	46.31
Performance margin, dB	1.10

Table 2. Forward link budget (NASA/LeRC to ACTS to aero terminal), aircraft flying from Washington, D.C./Cleveland, Ohio/Chicago, Illinois, with ground station at Cleveland, Ohio; clear weather with 4.8 kbps voice at BER = 10^{-3}.

Table 3. Return link budget (aero terminal to ACTS to NASA/LeRC), aircraft flying from Washington, D.C./Cleveland, Ohio/Chicago, Illinois, with ground station at Cleveland, Ohio; clear weather with 4.8 kbps voice at BER = 10^{-3}.

Uplink: Aero AMT to ACTS	Value
Transmitted EIRP, dBW	21.00
Pointing loss, dB	–0.50
Radome loss, dB	–1.00
Space loss, dB	–213.34
Frequency, GHz	29.63
Range, km	37,408
Atmospheric attenuation, dB	–0.46
Polarization loss, dB	–0.50
G/T, dB/K	15.00
Pointing loss, dB	–0.10
Bandwidth, MHz	900.00
Received C/N_0, dB-Hz	48.75
Transponder SNR_{in}, dB	–40.79
Limiter suppression factor, dB	–1.02
Downlink: ACTS to NASA/LeRC	**Value**
Transmitted EIRP, dBW	25.58
Pointing loss, dB	–0.50
Space loss, dB	–210.03
Frequency, GHz	19.91
Range, km	38,000
Atmospheric attenuation, dB	–0.38
Polarization loss, dB	–0.50
G/T, dB/K	28.50
Pointing loss, dB	–0.00
Downlink C/N_0, dB-Hz	71.28
Overall C/N_0, dB-Hz	47.68
Required E_b/N_0, dB	6.00
Modem implementation loss and loss due to phase noise, dB	2.50
Total E_b/N_0, dB	8.50
Fade allowance, dB	1.00
Data rate, kbps	4.80
Required C/N_0 efficiency, dB-Hz	46.31
Performance margin, dB	1.37

assumed. The required E_b/N_0 of 7 dB is needed to meet the required video codec BER of 10^{-6} — 1 dB higher than that needed to meet the 10^{-3} BER required in the low bit rate experiment. The modem implementation loss has been increased by 0.4 dB due to the higher data and Doppler rates associated with the high bit rate experiment. As in the low bit rate experiment, a loss of 1.2 dB due to phase noise will also be taken. The maximum EIRP of the AMT aeronautical terminal is assumed to be 32 dBW (obtained when the AMT TWT is set to its maximum output power). The radome loss for the AMT antenna is assumed to be 0.4 dB.

In the forward link, the fade allowance for the ground-to-ACTS-to-aircraft link will be decreased from 3.0 dB in the land mobile link to 1.5 dB, as less fading is foreseen during cruise. In the return link, the fade allowance and atmospheric loss are reduced to 1.7 and 0.3 dB from 3 and 0.61 dB, respectively.

ACTS' Cleveland, Ohio, fixed beam is used for communications with the LET and when the aircraft is above Cleveland. Its EIRP and G/T at the edge of beam are assumed to be 66.5 dBW and 19.5 dB/K, respectively. The link margin is also calculated when the aircraft is in the Los Angeles/San Diego beam. Its EIRP and G/T at the edge of beam are taken to be 62.5 dBW and 17.3 dB/K, respectively. In the link calculations, the aircraft is assumed to be at an altitude of 20,000 ft in clear weather.

The effect of the limiter in the ACTS transponder is dealt with as follows. For the two equal power signals transmitted in the forward link, the $EIRP_{out}$ at the output of the ACTS transponder can be written as [10]

$$EIRP_{OUT} = \left[\frac{EIRP_{MAX}}{2}\right]\gamma \qquad (1)$$

where γ is defined as

$$\gamma = \frac{\Gamma(SNR)_{IN}}{1+\Gamma(SNR)_{OUT}} \qquad (2)$$

where Γ is the limiter suppression factor. The limiter suppression factor varies depending on the input signal-to-noise ratio (SNR), the number of signals present and their relative power in the limiting channel [11–12].

Tables 4 and 5 show the link performance results for various locations of the aircraft and data bit rates for the forward and return link, respectively. The results show that the aircraft can receive data at 384 kbps or less if it uses ACTS' Cleveland fixed beam. When the aircraft uses ACTS' Cleveland fixed beam, it can receive data at 384 kbps and can establish duplex links at 112 and 64 kbps. When the aircraft accesses ACTS using the Los Angeles/San Diego scanning beam, it can receive data at 112 kbps, but can only maintain a duplex link at 64 kbps.

Effects of Rain Attenuation on Communications Link Availability

If we define

$(C/N_0)_T$ = total received carrier-to-noise ratio

$(C/N_0)_R$ = required carrier-to-noise ratio

$(C/N_0)_U$ = uplink received carrier-to-noise ratio without rain

$(C/N_0)_D$ = downlink received carrier-to-noise ratio without rain

A_U = uplink (NASA/LeRC-to-ACTS) rain attenuation

AD = downlink (ACTS-to-aircraft) rain attenuation

then the total received carrier-to-noise ratio can be calculated using the relationship [10]

$$\frac{1}{\left(\frac{C}{N_0}\right)_T} = \frac{1}{\left[\frac{1}{A_U}\left(\frac{C}{N_0}\right)_U\right]\Gamma} + \frac{1}{\left[\frac{1}{A_D}\left(\frac{C}{N_0}\right)_D\right]} \quad (3)$$

Let us define the link performance margin as

$$M(dB) = \left(\frac{C}{N_0}\right)_T (dB) - \left(\frac{C}{N_0}\right)_R (dB) \quad (4)$$

For the forward aeronautical link, the link from ACTS to the aircraft can be assumed to be rain free (i.e., the attenuation due to rain is negligible, $A_D = 1$). Hence, from Equation (4), we can show that the performance margin for the forward

ACTS antenna link bit rate, kbps	Link margin, dB	
	Los Angeles/San Diego hopping beam	Cleveland fixed beam
384	–0.2*	3.6
112	5.1	8.9
64	7.5	11.4

Table 4. Forward link margin results for various aircraft locations and data rates.

ACTS antenna link bit rate, kbps	Link margin, dB	
	Los Angeles/San Diego hopping beam	Cleveland fixed beam
112	–0.9*	1.1
64	1.4	3.5

Table 5. Return link margin results for various aircraft locations and data rates.

**Not possible.*

link, M_F(dB), can be approximated by

$$M_F(dB) = -10 \log\left[\left(\frac{C}{N_O}\right)_D + \frac{1}{A_U}\left(\frac{C}{N_O}\right)_U \Gamma\right] - \left(\frac{C}{N_O}\right)_R (dB) + \left(\frac{C}{N_O}\right)_U (dB) + \left(\frac{C}{N_O}\right)_D (dB) - A_U(dB) + \Gamma(dB) \quad (5)$$

Similarly, for the return link, we can assume that the rain attenuation from the aircraft to ACTS is negligible, i.e., $A_U = 1$, and that the return link performance margin, M_R(dB), is approximated by

$$M_R(dB) = -10 \log\left[\frac{1}{A_D}\left(\frac{C}{N_O}\right)_D + \left(\frac{C}{N_O}\right)_U \Gamma\right] - \left(\frac{C}{N_O}\right)_R (dB) + \left(\frac{C}{N_O}\right)_U (dB) + \left(\frac{C}{N_O}\right)_D (dB) - A_D(dB) + \Gamma(dB) \quad (6)$$

From Equations (5) and (6), we can determine the required value of the rain attenuation that causes the link performance margin to drop below 3 dB. Here, a 3-dB performance margin will be used as a conservative measure of maintaining the communications link with high quality. The plots of Equations (5) and (6) are shown in Figures 5 and 6, respectively, where the link performance margin is plotted as a function of rain attenuation for various data rates.

If we let A_{UT} and A_{DT} denote the threshold uplink (NASA/LeRC to ACTS) and downlink (ACTS to the aircraft), rain attenuation for both M_F(dB) and M_R(dB) will fall below 3 dB. The communication link availability is determined as the probability that the link margin is ≥3 dB due to rain attenuation. The link availability for the forward and return links are given by, respectively,

$$Pr\{A_U < A_{UT}\} = 1 - Pr\{A_U \leq A_{UT}\} \quad (7)$$

$$Pr\{A_D < A_{DT}\} = 1 - Pr\{A_D \leq A_{DT}\} \quad (8)$$

The probabilities $Pr(A_U \geq A_{UT})$ and $Pr(A_D \geq A_{DT})$ can be calculated using an annualized rain-fade model [7]. From [7], the communication link availability as a function of rain attenuation is plotted in Figure 7. The results for the forward and return link availabilities are summarized in Tables 6 and 7, respectively. It is shown that communications link availabilities for a 3-dB margin are 99.92 and 99.95% of the year for the forward and return links with 384 and 64 kbps, respectively.

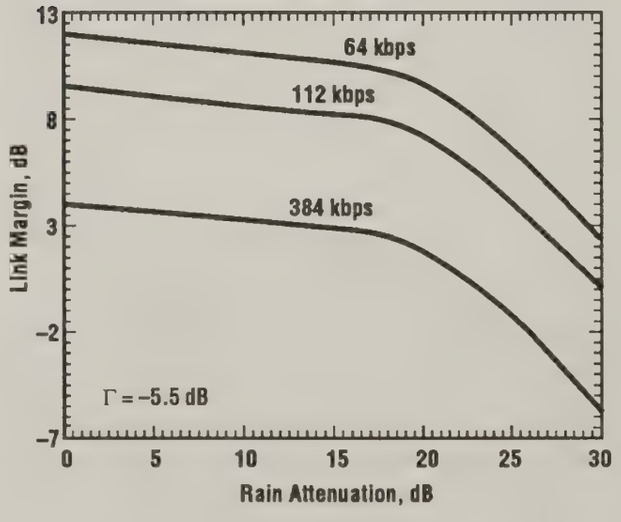

Figure 5. Forward link margin versus rain attenuation; aircraft is illuminated by ACTS' Cleveland, Ohio, fixed beam.

Summary

The low bit rate experiment, which is now being planned, will be principally a Ka-band technology demonstration of a prototype 4.8-kbps aeronautical mobile terminal using three experimental active electronically steered arrays. This experiment is scheduled for late 1993 or early 1994, and will use ACTS' west scan beam to maintain a link between an aircraft flying between Chicago, Illinois, Cleveland, Ohio, and Washington, D.C.

Data rate, kbps	Threshold value A_{UT}, dB	Link availability for 3-dB margin, % of year*
384	18.4	99.92
112	29.3	99.96
64	32.4	> 99.98

Table 6. Communication link availability, forward link using ACTS' Cleveland, Ohio, fixed beam.

Data rate, kbps	Threshold value A_{DT}, dB	Link availability for 3-dB margin, % of year*
112	Not applicable	Not available
64	21.3	99.95

**Annualized average.*

Table 7. Communication link availability, return link using ACTS' Cleveland, Ohio, fixed beam.

The high bit rate experiment, under a proposal to NASA, would demonstrate a 64–384-kbps satellite link between an aircraft and a ground terminal. The aeronautical terminal for this experiment would utilize the majority of the Ka-band equipment under development at JPL for the ACTS land mobile terminal, including its mechanically steered antennas. The aircraft would access ACTS via the Cleveland fixed beam or any of the individual beams produced by the east scan sector beam-forming network. Three bit rate options (384 kbps/112 kbps, 112 kbps duplex and 64 kbps duplex) have been identified for this experiment. These options trade experimental objectives with terminal cost.

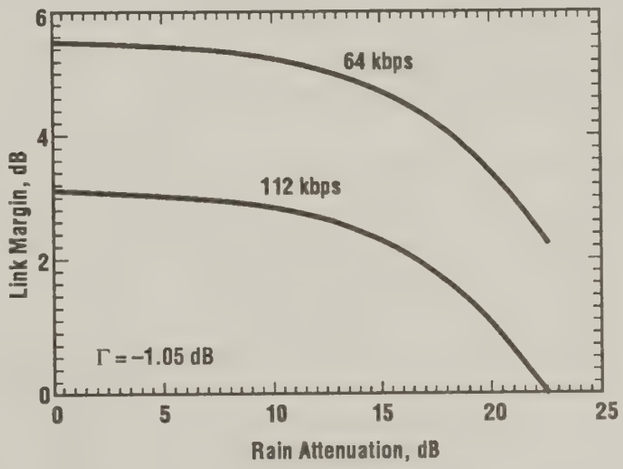

Figure 6. Return link margin versus rain attenuation; aircraft is illuminated by ACTS' Cleveland, Ohio, fixed beam.

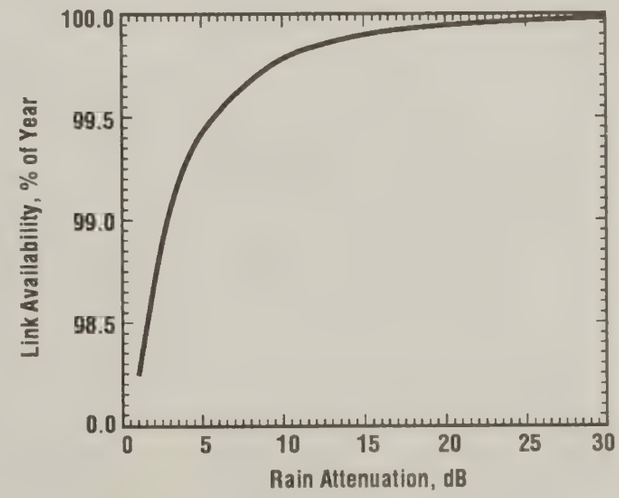

Figure 7. Communication link availability versus rain attenuation, assuming fixed Earth station in Cleveland, Ohio, and an uplink frequency of 29.63 GHz.

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Ka-Band Phased Array Feed for NASA Deep Space Applications

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Ka-band telecommunications systems will be developed for future deep space missions to increase the downlink data rate, reduce hardware size and provide accurate antenna pointing. The usefulness of electronic beam steering depends on system requirements in pointing accuracy, system mass and DC power consumption. A tradeoff between electronic beam steering and attitude controls requires a careful examination of these areas. The current spacecraft pointing resolution requirement is 0.05 deg. A simpler, lighter system for coarse pointing could be supplemented by beam steering from a phased array, which could reduce the mass, DC power requirements and complexity of the attitude control system.

A phased array feed at the focal point of a Cassegrain antenna system provides electronic beam steering and transmit power amplification from low-power monolithic microwave integrated circuit (MMIC) amplifiers and spatial power combining. The feed shown schematically in Figure 1 has 21 antenna elements, each excited by a cascaded phase shifter and amplifier string. A 21-way beam-forming network (BFN) channels equal levels of power and phase signals to each path.

The array architecture is modular for ease of testing and to provide a testbed for new technology insertion. The array comprises seven trays or modules containing dummy-3-5-5-5-3-dummy elements, respectively. Dummy elements are included on the top and bottom trays to increase gain through mutual coupling and to improve the symmetry of the array. Each tray consists of power divider, phase-shifter, power amplifier and antenna submodules, as shown in Photo A.

A Ka-band MMIC 4-bit phase shifter provides the beam steering capability. The phase shifter is controlled by a digital application-specific integrated circuit (ASIC), which receives a serial data stream and converts it to parallel data, as required by the MMIC. Power amplifiers are pseudomorphic high electron mobility transistor (PHEMT) MMICs with state-of-the-art power efficiency performance.

Ka-Band 4-bit MMIC Phase-Shifter Module

Electronic beam steering of ±5 deg can be provided by the phase-shifter module shown in Photo B. Each path in the module consists of a GaAs MMIC phase shifter, a complementary metal oxide semiconductor (CMOS) ASIC control chip and a 50-ohm transmission line fabricated on a 0.25-mm–thick alumina substrate. The alumina substrate is laser cut to provide wells for the MMIC chips and openings for the control signal feedthrough. The MMIC phase shifter and ASIC are interconnected by control lines etched in the alumina and by a multilayer substrate recessed beneath the RF substrate. Interconnections to the recessed substrate are via gold bond wires. The phase shifter, developed by Honeywell, was measured in the module and results are shown in Figures 2 and 3. At 32 GHz, the average insertion loss is –11.5 to –14 dB and average phase deviation is ±10 deg.

The advantages of using MMIC-based modules include electronic beam steering, efficient low-power amplifiers and small size.

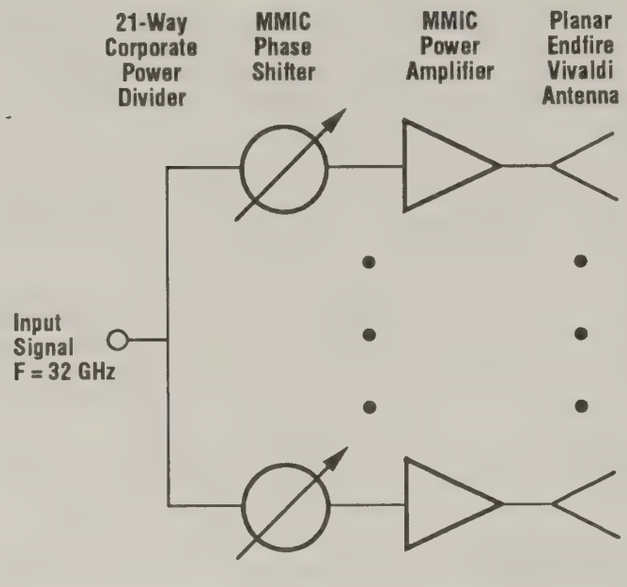

Figure 1. Schematic representation of 21-element phased array antenna feed.

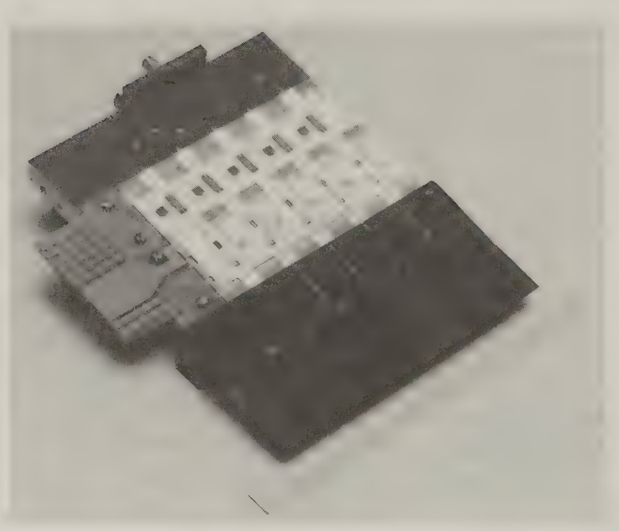

Photo A. Single five-element module consisting of microstrip BFN, phase-shifter module, power amplifier module and Vivaldi antenna module.

Ka-Band MMIC Power Amplifier Module

Recent efforts have been primarily directed toward power amplifier module integration. Recent research [1,2] at Texas Instruments (TI) has produced a chip set (a driver stage and a high power stage) capable of delivering 350 mW of RF power at 31.5 GHz. The first approach was to cascade the two devices using microstrip transmission lines etched on 0.25-mm alumina substrates as interconnects. Input, output and interstage matching would also include external tuning. Power output of 350 mW was demonstrated [3] in a 50-ohm test fixture. However, upon integration with the antennas and phase-shifter modules, destructive oscillations were observed and the approach was reevaluated.

A complete evaluation of the modules was conducted, including consultation with HEMT amplifier device physicists at JPL, TI and other leading institutions. Several possible conditions were identified that could have contributed to the oscillations. There are 21 active elements in the array; biasing each amplifier with a common supply reduced the number of connections but can provide a feedback path. The high-power amplifier stage did not incorporate on-chip bias decoupling circuitry. Drain bias for this stage was provided through an RF-shorted, quarter-wavelength high-impedance line on the output transmission line. A feedback path from the drain bias line of the high-power stage to the drain bias line of the low-power stage was also identified. The common drain line between the two amplifiers did not provide sufficient RF filtering to suppress RF leakage from the RF chokes or from RF radiation and surface-wave coupling.

Two other conditions that may have led to destructive oscillations during integration are the input and output load impedances presented to the amplifier module by the antenna and phase-shifter modules. Out-of-band load conditions have been reported as a source of oscillations [4]. Although the devices were designed to be unconditionally stable, changes in bias circuitry loading of the RF circuit, combined with external tuning and narrowband loads, certainly contributed to the unwanted conditions. These conditions were duplicated at TI on individual stages. Given the unsuspected complications of cascading two amplifier MMICs, the approach taken to complete the array was to trade away the higher power capability and replace the power stage with a 50-ohm transmission line. The lower power device was designed with on-chip bias decoupling circuitry and has been shown to be stable under all load conditions presented to the device. A suitable high-power output device can be inserted at a later time.

The MMIC power amplifiers provide over 2 W of total transmit power to the antenna modules. Each amplifier consists of a three-stage design, as shown in Photo C. The final stage is a 250-μm HEMT with a 1-dB compression point greater than +20 dBm, a power-added efficiency of

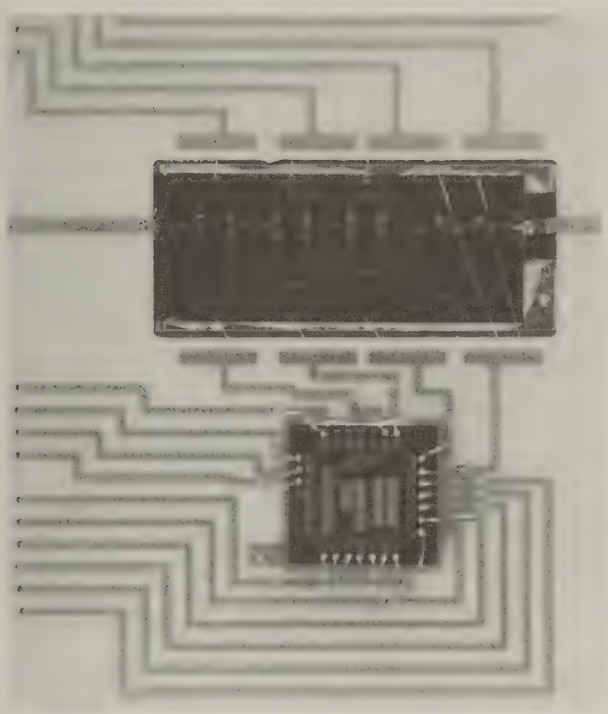

Photo B. MMIC phase-shifter module showing five phase shifters and digital ASIC control chips.

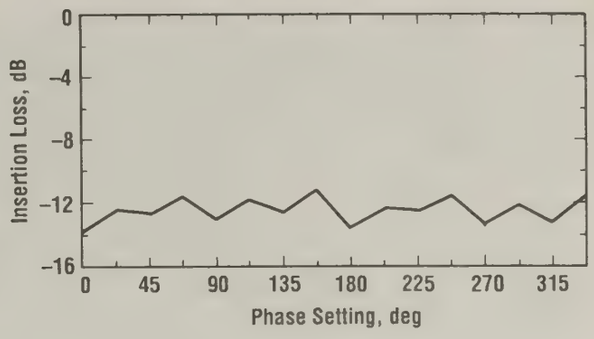

Figure 2. Average insertion loss performance of MMIC phase-shifter module at 32 GHz.

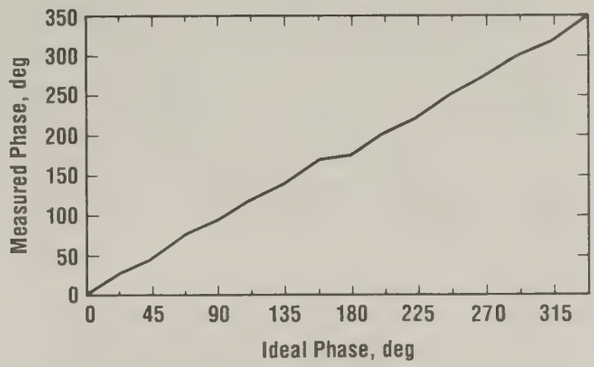

Figure 3. Average phase-error performance of MMIC phase-shifter module at 32 GHz.

18 percent and a gain of 19 dB in the module. The peripheral dimensions of the chip are 0.236 × 0.104 × 0.010 cm. The amplifiers are mounted on copper subcarriers using a eutectic die attach process; the subcarriers are then epoxied into a molybdenum carrier. Module interconnecting transmission lines are fabricated on 0.25-mm alumina substrates, which are also epoxied to the molybdenum carriers. External tuning is required to adjust for bond wire and interconnect discontinuities, but the tuning pad location is fairly consistent from device to device. The measured results for a single amplifier submodule are shown in Figures 4 and 5.

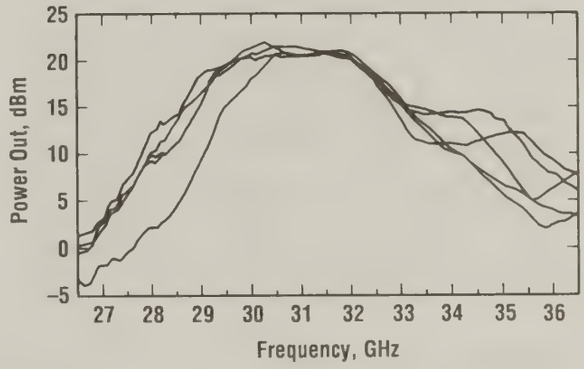

Figure 4. Measured RF power output of five paths on a typical MMIC amplifier module.

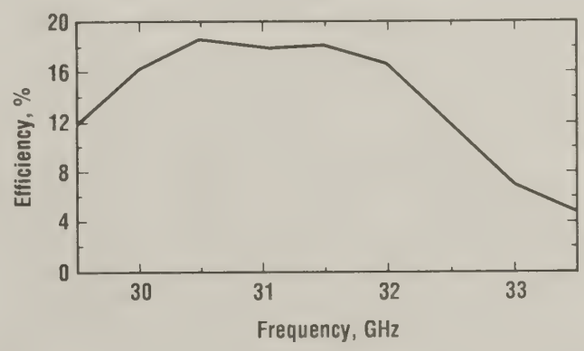

Figure 5. Efficiency measurements for MMIC power amplifier module.

Phased Array Integration

Module BFNs consist of microstrip 3-way and 5-way power dividers fabricated on 0.125-mm duroid laminated on aluminum. The antennas are Vivaldi slotline end-fire radiators [5] with microstrip-to-slotline transitions. The BFN, phase shifter, amplifier and antenna integration consists of mechanical assembly using a precision shoulder screw for alignment and module interconnection with gold ribbon.

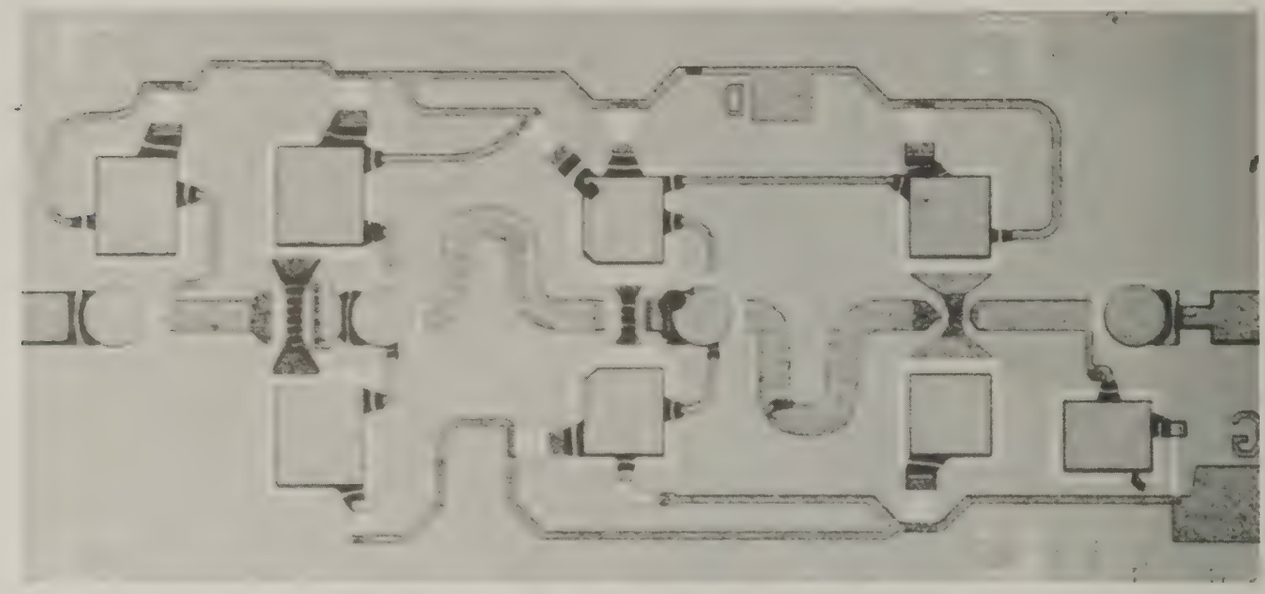

Photo C. Texas Instruments 100-mW, three-stage HEMT MMIC power amplifier.

An open architecture was selected for this project to allow maximum flexibility in tuning and modularity. To reduce crosstalk between element paths and radiation from microstrip bends and discontinuities, channelized covers made from absorbing material (Eccosorb MF 124) are placed over each module. The covers provide an additional 5 to 10 dB of isolation between paths. Three amplifier modules have been assembled and tuned with no further problems with oscillations. The amplifiers will now be integrated with the antennas and range measurements will be made.

Conclusion

The results to date demonstrate the performance of MMIC-based modules in a low-mass, low-volume transmit array architecture. Distinct advantages include electronic beam steering, highly efficient low-power amplifiers and small package size.

The Ka-band MMIC phase shifter provides electronic beam steering capability under computer control with an average insertion loss of –11.5 to –14 dB and an average phase deviation of ±10 deg at 32 GHz. MMIC power amplifiers with 100-mW RF power output and 18-percent efficiency are spatially combined to achieve over 2 W of total transmit power. This combination, together with the high-gain (24.2 dBi) Vivaldi antenna, provides transmit EIRP of 27.2 dBW.

Acknowledgments

The MMIC phase shifters were developed by Honeywell under contract to the NASA Lewis Research Center (LeRC). The MMIC power amplifiers were developed by Texas Instruments under contract to LeRC.

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The 1992 World Administrative Radio Conference: New Allocations and New Challenges

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The 1992 World Administrative Radio Conference (WARC), convened by the International Telecommunication Union (ITU), was held February 3 through March 3 in Torremolinos, Spain. The Conference established new frequency spectrum allocations for a wide range of satellite communications services to be offered through a vast array of new technologies and systems. This was the first Conference since 1979 to consider allocations throughout the spectrum and is likely to be the last Conference of its kind; its actions, however, will affect satellite communications systems and services through the remainder of this century and beyond. The complexity of the Conference's agenda is reflected in the complexity of its resulting decisions, which will present a variety of challenges in the design and definition of future satellite communications services and systems.

Conference Preparations and Objectives

The ITU, an organization within the United Nations, convenes periodic Administrative Radio Conferences to construct agreements among member nations on the use of the radio frequency spectrum for communications purposes. The 1992 World Administrative Radio Conference for Dealing with Frequency Allocations in Certain Parts of the Spectrum dealt with an agenda that was complex in the diversity of services considered and wide ranging in the portions of the spectrum examined [1]. The 1992 WARC agenda mandated

- Definitions for new space applications.
- Allocations above 20 GHz to new space applications.
- Allocation of frequency bands to the Broadcast Satellite Service (BSS) (Sound) in the range of 500–3000 MHz.
- Allocations for wide-RF-band high-definition television on a worldwide basis.
- Allocation of frequency bands to the Mobile and Mobile Satellite Services (MSS) in the approximate range of 1–3 GHz, including low Earth orbit (LEO) MSS systems and Future Public Land–Mobile Telecommunications Systems (FPLMTS).
- Allocations below 1 GHz to LEO MSS systems.
- Addressing the imbalance in Ku-band Fixed-Satellite Service uplink and downlink frequency bands.
- Examination of the frequency bands 2025–2110 and 2200–2290 MHz for Space Operation and Space Research Services.

The United States spent approximately two years preparing for the 1992 Conference. Preparations included both domestic and international activities designed to establish the technical bases for decisions of the Conference and to develop and disseminate U.S. views on Conference issues.

The Department of State provided the overall coordination of U.S. preparation for and participation in the Conference. U.S. Government–sector preparations were initiated in Ad Hoc Committee 206 of the Interdepartmental Radio Advisory Committee and on behalf of the private sector by the

Federal Communications Commission through its Notices of Inquiry and Industry Advisory Committee [2,3,15]. These efforts were later consolidated within U.S. Allocations, Regulatory and Technical Committees under the U.S. WARC–92 Preparatory Group and, eventually, under the U.S. Delegation to WARC–92 chaired by Ambassador Jan Witold Baran.

GSS would accommodate both fixed and mobile satellite applications, including VSATs and personal access communications.

NASA's key WARC objectives for commercial satellite communications services included establishing a definition and allocation at 19.7–20.2/29.5–30.0 GHz for the General Satellite Service (GSS) to provide for a new generation of commercial communications satellites building upon Advanced Communications Technology Satellite (ACTS) technology to provide a flexible mix of fixed and/or mobile applications; establishing a suitable BSS (Sound) frequency allocation for the provision of Direct Broadcast Satellite–Radio (DBS–R) as an objective of the joint NASA/Voice of America DBS–R Program, and establishing an allocation for uplink power control beacons beneficial to propagation researchers and commercial Ka-band communications satellite networks of the future.

The NASA Office of Commercial Programs and the NASA Lewis Research Center participated in a comprehensive series of domestic and international WARC preparatory activities. These activities included participation in Interdepartmental Radio Advisory Committee Ad Hoc 206 and the FCC Industry Advisory Committees, preparation of NASA responses to FCC Notices of Inquiry, participation in U.S. Allocations, Technical and Regulatory Committees and participation in the U.S. WARC–92 Delegation. NASA wrote, cowrote or provided input to U.S. WARC–92 positions on the GSS definition, GSS allocation, technical characteristics of the GSS, uplink power control beacons, feeder links for the MSS (LEO and geostationary) and the proposed frequency allocation for the BSS (Sound).

NASA's international activities included preparation of U.S. technical input and participation in the U.S. delegation to the Joint Interim Working Party (JIWP) 10-11/1 of the International Radio Consultative Committee (CCIR) responsible for BSS (Sound) [4–6,10]; preparation of U.S. position papers on BSS (Sound) and the GSS for meetings of the Organization of American States' telecommunications committee (CITEL); participation as a U.S. delegate and spokesman to CITEL's final WARC preparatory meeting, and preparation of U.S technical input on the BSS (Sound) to the CCIR JIWP WARC–92 [12]. The Jet Propulsion Laboratory also prepared a number of CCIR technical inputs on BSS (Sound) [7–9,13,14] and GSS services [18] and presented papers on these topics at CITEL.

NASA internal preparations for the Conference included a presentation to Ambassador Baran, shortly after his appointment as the U.S. Delegation Chairman, on NASA objectives for the WARC, including a BSS (Sound) allocation and establishing the GSS, and a presentation to the NASA Administrator on NASA's role in and objectives for WARC–92 [11,16,17].

The General Satellite Service

The United States, Canada and Mexico proposed the definition of a new satellite service — GSS or Multipurpose Satellite Service. Rapidly evolving technologies are blurring the distinction between what have, until now, been regarded as distinctly fixed or mobile communications applications. GSS would accommodate both fixed and mobile satellite applications, including very-small-aperture terminal (VSAT) communications, communications with small portable terminals and personal access communications. Allocations to this new service were proposed at 19.7–20.2/29.5–30.0 GHz, the frequency bands to be used by ACTS to demonstrate both fixed and mobile communications capabilities. These frequency bands were proposed for allocation to GSS because of a highly developed technology base and because satellite transmissions in these bands are not subject to power flux density limits — which would preclude the use of spectrum and orbit-efficient spot-beams necessary for achieving communications at the personal level.

At the Conference, discussion of the GSS definition and allocation proposals encountered strong opposition on the part of the Conférence Européenne des Administrations des Postes et des Télécommunications (CEPT) administrations (32 nations). A European Common Position (ECP) supported "no change" to existing Fixed-Satellite Service primary and MSS secondary allocations at 19.7–20.2 and 29.5–30.0 GHz. Opposition was based on two considerations: concern regarding GSS compatibility with anticipated implementation of VSATs in the 20/30-GHz bands in Europe and a perceived lack of need for a new satellite service definition.

GSS proponents asserted that the GSS would not only fully accommodate VSAT networks but would benefit network operators by providing a means by which they could reach a wider range of user terminals. GSS proponents also vigorously advocated the new service definition as an appropriate change to the Radio Regulations that would simplify the process of bringing satellite networks capable of multiple applications into use, resulting in economic benefits for both industrialized and developing nations. The new service definition was also advocated as the most appropriate means of establishing a regulatory framework that recognizes that satellite networks capable of multiple applications not only exist, but will only increase in number [19,20].

The efforts of GSS proponents at WARC–92 can be described, on a practical basis, as largely successful. An upgrade of the Mobile Satellite Service allocation to coprimary status with the Fixed-Satellite Service was achieved in the bands 19.7–20.2/29.5–30.0 GHz in ITU Region 2 and in the bands 20.1–20.2/29.9–30.0 GHz in Regions 1 and 3. Thus, substantial opposition to any change to allocations at these frequencies was overcome. Footnotes attached to the new MSS allocations specifically provide for their use in satellite systems capable of both fixed and mobile applications. These allocations represent significant progress in accommodating GSS applications in Region 2 and permit introduction of GSS applications in Regions 1 and 3. The Conference also recommended that an appropriate future Conference consider defining a general or multipurpose satellite service and consider allocating additional spectrum to accommodate growth of multipurpose satellite networks.

While work remains to be done in order to formally establish GSS on a worldwide basis, major steps toward this objective were accomplished at the 1992 WARC.

An Allocation to the Broadcast Satellite Service (Sound)

Establishing the technical basis for an allocation to the BSS (Sound) in the 500–3000 MHz portion of the spectrum has been a critical element of the joint NASA/Voice of America DBS–R Program. NASA supported the establishment of an appropriate allocation to the BSS (Sound) as an integral element in creating new opportunities for U.S. industry to participate in the provision of a new satellite communications service, both domestically and to a global marketplace. One very important potential benefit of the service is that large audiences can gain increased access to cultural and educational programming.

Determining a new allocation for the BSS (Sound) within the 500–3000 MHz portion of the spectrum was a particularly difficult task for administrations (i.e., the delegations from various nations), during both Conference preparatory efforts and at the Conference itself. Complexities were introduced both by demands upon this portion of the spectrum for the provision of new services and the need to protect a variety of existing services. The Conference also needed to consider new allocations in this portion of the spectrum for terrestrial Mobile Service (i.e., FPLMTS) and Mobile Satellite Services provided by systems in geostationary and nongeostationary orbits. However, the 500–3000 MHz portion of the spectrum is currently used by a diverse set of existing services, including terrestrial fixed services, UHF broadcasting, terrestrial mobile services, mobile satellite services, maritime mobile satellite services and aeronautical mobile services. Since each nation's investment in such services may vary, each nation's prioritization of spectrum for existing services versus spectrum for new services, and spectrum for one new service versus another, must vary as well. These considerations shaped each administration's proposal for a BSS (Sound) allocation brought to the 1992 WARC and limited their flexibility to agree on a worldwide allocation.

Proposals discussed at the Conference centered on three principal regions of the 500–3000 MHz portion of the spectrum. The United

States proposed that the band 2310–2360 MHz be allocated to BSS (Sound). A number of European and Asian administrations proposed allocations in bands centered at approximately 2600 MHz. A large number of administrations of the Americas, Africa and the Pacific Rim favored an allocation near 1500 MHz.

After extensive efforts, allocations to BSS (Sound) were achieved that will meet most administrations' needs. The Conference provided an allocation to BSS (Sound), which most nations will use, at 1452–1492 MHz. Due to the need to preserve existing services in this frequency band, the United States will use the band 2310–2360 MHz; several ITU Region 3 countries and the Russian Federation will use the band 2535–2655 MHz. The upper 25 MHz of each of these bands will be available for near-term implementation of BSS (Sound) systems, prior to a planning Conference for all BSS (Sound) bands to take place by 1998.

These allocations represent the outcome of more than 25 years of discussion of satellite sound broadcasting service within the ITU and will permit DBS–R services to be implemented worldwide — subject to extensive provisions for the protection of existing services.

The challenge was that of responding to changing technologies capable of providing an evolving array of services while also responding to continuing needs for established services.

Allocations for Uplink Power Control Beacons

New allocations were established by the Conference providing frequency bands that may be used for uplink power control beacons on a worldwide basis. These new allocations will benefit propagation research efforts conducted using Ka-band satellite systems such as ACTS and OLYMPUS, and will benefit future commercial operation of Ka-band satellite communications systems as well.

The United States, Canada, Japan, Australia and European nations came to the Conference with specific proposals for frequency bands to be allocated for use by uplink power control beacons. The United States and Japan proposed that space-to-Earth beacons be permitted to operate throughout the band 27.5–29.5 GHz. Canada proposed that the bands 27.500–27.501 and 29.999–30.0 GHz be allocated on a primary basis for use by beacons. Australia proposed that beacon operations be permitted in the bands 27.0–27.001 GHz in ITU Regions 2 and 3 (i.e., the Western Hemisphere, Asia and the Pacific), bands 27.5–27.501 GHz in Region 1 (Europe and Africa) and bands 30.999–31.0 GHz worldwide.

Allocations that satisfied all participants were identified and adopted by the Conference. The bands 27.5–27.501 and 29.999–30.0 GHz were allocated on a primary basis for use by uplink power control beacons; the entire 27.501–29.999-GHz band was also allocated for use by uplink power control beacons on a secondary basis. These allocations provide great flexibility for the placement of beacon signals within the spectrum and accommodate beacon frequencies in use by OLYMPUS (29.65 GHz) and those that will be used by ACTS (27.505 GHz).

Frequency bands to be used for uplink power-control beacons were among the earliest allocation decisions approved by the Conference. By adopting these allocations, the 1992 World Administrative Radio Conference recognized the importance of the availability of spectrum for uplink power control beacons for propagation research and for the commercial Ka-band systems of the near future.

Future Conferences

The 1992 WARC approached a variety of challenges in establishing new allocations for a variety of communications services. The challenge that seemed to present the greatest difficulty was that of responding to rapidly changing technologies capable of providing an evolving array of services while also responding to continuing needs for established services in which there are considerable investments. The ITU is currently undergoing restructuring in order to make the organization more responsive to rapidly evolving technologies, to be

more cost effective and to be more responsive to the particular needs of developing nations. Future ITU Conferences are likely to be shorter in duration (approximately two weeks) and to occur more frequently (approximately every two years) [21]. More frequent Conferences, while offering the opportunity to revise the Radio Regulations at a pace more consistent with changes in technology, will pose a challenge to administrations to maintain ongoing Conference preparatory efforts.

Additional challenges were presented to the Conference by issues of competition — not the customary and ongoing need to resolve competition between services for scarce spectrum resources, but the newer issue of international competition within the marketplace. Not surprisingly, economic agendas of nations are likely to play an increasingly important role in defining the regulatory agendas with which they approach each Conference. Economic alliances between nations are likely to result in alliances on regulatory positions, which will influence and perhaps determine Conference decisions as well.

These broad challenges must be taken into account as future Conferences approach issues of interest to the United States and to NASA's Commercial Communications Program — such as establishing the GSS and planning the BSS (Sound) services.

Future Satellite Systems and Services

The decisions of the 1992 Conference have established the international regulatory environment under which a variety of new satellite communications services and systems will operate. The decisions reflect the complexity of the issues that the Conference was required to address.

BSS (Sound) will be provided within three distinct frequency bands. Each band has frequency-dependent attributes, ranging from propagation characteristics to power requirements for beams designed to serve a specific coverage area. These attributes impact system cost. A challenge posed by the allocation decisions of WARC–92 for implementers of BSS (Sound) systems will be to continue to seek and develop technologies designed to reduce and equalize ground and space segment costs regardless of operating frequency.

GSS has yet to be established on a formal basis, although the decisions of WARC–92 can be regarded as establishing the service on a de facto basis. The challenge to be met in establishing a new service definition responsive to the rapid evolution of space and ground segment technologies at 20/30 GHz will be the demonstration of flexibility and efficiency to be gained by accommodating a range of user services in a single network and the demonstration that a variety of such networks can be operated on a compatible basis. With the launch of ACTS in 1993, that challenge will begin to be met.

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Contract Let to the Pacific Advanced Communications Consortium

Laura C. Steele, Managing Editor
Jet Propulsion Laboratory

JPL has released a study contract to the Pacific Advanced Communications Consortium (PACC) to examine the use of satellites in personal communications networks (PCNs) for rural users. PACC is a consortium that comprises Oregon and Washington communications companies, universities and government agencies. Its primary objectives are to promote

- Implementation of socially and economically beneficial advanced telecommunication and computer applications ("telematics") in the Pacific Northwest.
- Communication equity among users, especially between rural and urban users.
- Research on telematics issues and applications.
- Development of technically and economically efficient advanced communication hardware, software, subsystems and services.
- Further development of the Pacific Northwest telematics industry.
- Public "information-age" education.

PACC was formally organized in April 1991 and is now engaged in several telecommunications projects, including the establishment of an advanced communications infrastructure in a rural area as a test site for economic growth. The infrastructure is currently under development and will consist of interactive compressed video, high-speed data capabilities and electronic mail to provide instant audio and video connections to rural schools, medical facilities, businesses and residences. If successful, the concept will be expanded to other rural areas, both domestic and international. Another potential project involves the evaluation of the feasibility of using NASA's Advanced Communications Technology Satellite (ACTS) as a backup to terrestrial communications services during disasters.

For the JPL study, PACC will examine the role of satellites in remote and rural personal communications networks, with a primary emphasis on users in the Pacific Northwest. A user needs assessment will be conducted to determine potential thin route users of PCNs, communication needs, service parameters and acceptable costs, as well as the level of satisfaction with present communications systems. Communications systems users in various public service agencies, including police, forestry, agriculture and utilities will be interviewed. Private industry, such as logging and mining companies, will also be asked to participate in the assessment.

Based on the results of the user needs assessment, PACC will examine appropriate communication networks and their tradeoffs. Of primary concern will be the tradeoffs between different types of satellites (low-Earth orbit, geostationary, bent-pipe, etc.) and multiple-access schemes (TDMA, CDMA, Aloha, Spread-Aloha, etc.). Protocol problems in interacting with other systems will also be examined.

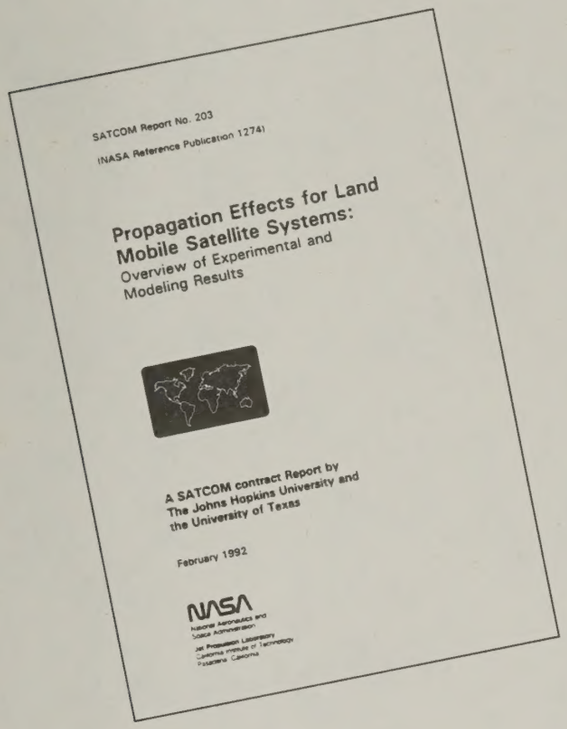
The resulting user needs solutions will then be used as the basis for determining possible national and international applications for satellite

PCNs. Various experimental scenarios utilizing ACTS and appropriate terminals may be devised to demonstrate personal access satellite system technology.

Dr. Deanna Campbell Robinson, University of Oregon, is the director of PACC and will lead the research effort. She specializes in comparative and international policy strategies for using telecommunications to encourage economic development. She will be supported by David Povey, Director of the Community Planning Workshop at the university. Technical consultants include Dr. Norm Abramson of the University of Hawaii, an acknowledged expert on networking and access protocols, and Dr. Ed Parker, Parker Telecommunications, a former Stanford University professor and founder of Equatorial Communication. PACC will also be supported by industry, including representatives from US West Advanced Technologies, Northern Telecom, GTE, Pacific Telecom/Alascom and Tektronics, and by the Economic Development Offices of both Oregon and Washington.

New SATCOM Document

The following new document is available from the JPL SATCOM Publications Office. Please use the order form on the inside of the mailing cover to order by title and/or number.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A SATCOM contract Report by
The Johns Hopkins University and
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February 1992
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Propagation Effects for Land Mobile Satellite Systems: Overview of Experimental and Modeling Results

This document was produced by the Johns Hopkins University Applied Physics Laboratory and the University of Texas Electrical Engineering Research Laboratory in February 1992, under joint contract from the NASA Headquarters Office of Commercial Programs and the Jet Propulsion Laboratory. Request SATCOM Publication 203 (125 pages).

The document is also available from NASA Headquarters as NASA Reference Publication 1274.

Erratum

On page 16 of the April *SATCOM Quarterly*, in the article entitled "Satellite Uplink Power Control," Equation (9) contained an error. Equation (9) should have read:

$$\frac{d\alpha(t)}{dt} = 1.5\times10^{-3}\{a(f)R^{b(f)}\}\ \bar{v}_d \left(\frac{b}{a}\right)\left[1-\left(\frac{a-t\bar{v}_d}{a}\right)^2\right] \qquad (9)$$

As printed, the "$\times 10^{-3}$" was omitted.

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IMSC '93 Planned for June

The Third International Mobile Satellite Conference (IMSC '93) and Exhibition is planned for June 16–18, 1993, in Pasadena, California. IMSC '93 will serve as a forum to review and demonstrate the design, development and applications of mobile satellite systems and associated regulatory and policy aspects of this technology. In particular, the conference will focus on the growing satellite communications industry.

The call for papers will be mailed in September. For more information, contact the Organizing Committee:

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